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Abstract. During the summers of 1967 and 1968, digestion rate and daily food consumption of yearling black bullheads (*Ictalurus melas*) fed chironomid larvae in the laboratory were compared with similar data for bullheads feeding in Clear Lake. Fish were starved for 3 days and force-fed 0.20 g or 0.30 g of chironomid larvae (*Chironomus riparius*). Stomachs were mostly empty of food 12 hours after force-feeding. Analysis of covariance showed that the amount of food digested depended on the weight of food fed and time allowed for digestion. Tripling the size of the force-fed meal increased digestion rate 2.4 times. The Bajkov (1935) method indicated digestion rate was slower for fish feeding naturally in the lake.

When food was more abundant, daily food consumption in the laboratory for fish fed either 3- or 6% body weight rations of chironomid larvae increased to 5.6% body weight in turbid lake water and 3.6% in nonturbid tap water. Fish sampled in the lake had a daily average of 1.78% of their body weight or 0.24 g of food in their stomachs with peaks of feeding at 1:00 AM and 5:00 PM. Daily food consumption was 0.77 g of food or 5.6% of body weight.

Forney (1955) outlined the life history of the black bullhead (*Ictalurus melas*) in Clear Lake and found that chironomid larvae were their main food. Channel catfish (*Ictalurus punctatus*), yellow bass (*Morone mississippiensis*), largemouth bass (*Micropterus salmoides*), bluegill (*Lepomis macrochirus*), yellow perch (*Perca flavescens*) and carp (*Cyprinus carpio*) also utilize chironomids in Clear Lake (Ridenhour, 1960; DiCostanzo, 1957; Parsons, 1950; Effendie, 1968). Information on the feeding intensity of bullheads would help determine their role in relation to the more desirable fish.

This study was started in the summer of 1967 of investigate digestion rate and daily food consumption of yearling black bullheads fed chironomid larvae in the laboratory. Comparisons were made with bullheads feeding naturally in the lake.

Materials and Methods

All experiments were performed with fish of age group I ranging in total length from 7.6 to 14.5 cm and in live weight from 4.4 to 28.5 g. Before experimentation fish were acclimated in a 1.52 m long, 0.91 m wide fiberglass tank containing water to the depth of 0.23 m. Aeration was not necessary with constant water exchange. For digestion rate experiments, the tank was divided

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into six equal compartments, and at night the top of the tank was covered with a black plastic sheet to exclude artificial light. Feeding rate experiments were performed in twelve 5-gal. glass aquaria provided with aeration and continuous water flow maintaining a depth of 19 cm. The sides of the tanks were covered at all times with black plastic and the tops were similarly covered at night.

Chironomid larvae (*Chironomus riparius*) used as experimental food organisms were not obtained from the lake because of greater abundance and easier collection in the trickling filters at the Clear Lake Sewage Treatment Plant and in nearby streams. Large samples of larvae were kept in a refrigerator at 7° C for over a week without significant emergence or death. Chironomid larvae were blotted with absorbent paper before weighing on a triple beam balance accurate to 0.01 g. Although larvae of various sizes were used, they averaged 228 larvae per gram.

The Force-feeding Method. Fish were kept in the holding tank for a 3-day starvation period before experimentation to remove food present in the intestinal tract (Hunt, 1960). Digestion rate experiments involving force-feeding (Baur, 1969) were performed after 7 PM to coincide with the natural feeding time of the bullheads (Darnell and Meierotto, 1965). Larvae regurgitated by each fish after force-feeding were weighed to determine the actual amount of food retained.

Five fish, each bearing a different colored thread in the caudal fin, were placed in each of the six compartments in the fiberglass holding tank. Lake water in the tank was kept between 21 and 24° C. Fish were randomly selected for stomach examination after allowing 2, 4, 6, 8, 10, or 12 hours for digestion. Stomachs were removed from the fish at the preselected time and their contents blotted with absorbent paper before weighing.

Digestion rate was considered in terms of stomach evacuation (Hunt, 1960) and expressed as grams of food evacuated by the stomach per hour or as percentage stomach evacuation per hour.

The Bajkov Method. Digestion rate of fish feeding in the lake was determined by the Bajkov (1935) method. To obtain fish after they had been feeding, 55 bullheads were collected after 9 PM and kept in lake water between 22 and 25° C in the fiberglass holding tank. At each of five time periods, 0, 2, 4, 6, and 8 hr. after capture, 11 bullheads were killed by a spray of hot water. Although this method of killing fish by scalding with hot water has not been mentioned previously in the literature, it proved very reliable for quickly killing large numbers of fish simultaneouly without apparent regurgitation of stomach contents. Stomachs were removed and placed in 10% formalin solution for not more than 24 hrs. before examination. Stomach contents were blotted with absorbent paper, weighed, and grossly examined for kinds of food eaten. Results were considered in terms of weight of food recovered.

Daily Food Consumption Determined in the Laboratory. Bullheads were anesthetized with a 0.01% solution of Tricaine Methanesulfonate (MS - 222) to facilitate measurement of lengths and weights. Daily rations of 3% body weight were given to one-half of the test fish and the remaining fish received 6% body weight ration.

Chironomid larvae were placed in the tank daily at 12 noon, when little feeding activity by bullheads normally occurs (Darnell and Meierotto, 1965), to allow the larvae to become dispersed on the bottom of the tank. Before adding the fresh ration, all uneaten larvae were removed and weighed to determine the exact amount of food eaten in a 24-hour period. The percentage to body weight of food consumed was then determined.

Daily Food Consumption Determined in the Lake. Daily food consumption and diurnal feeding activity were determined with fish feeding naturally in the lake. Samples of 9 to 11 fish were collected in Clear Lake for 24 non-consecutive hourly periods during August 20 to 22nd. During this time, the lake water temperatures ranged between 25 and 27° C.

Stomachs were removed from the fish immediately upon capture and placed in 10% formalin for up to 48 hr., at which time their contents were examined and weighed. The contents of the 11 stomachs obtained in one time period were weighed together and the mean was calculated.

Results

Digestion Rate by the Force-feeding Method. Digestion rate data were collected from 74 fish ranging in total length from 8.3 to 10.7 cm (mean 9.2 cm) and force-fed 0.20 g or 0.30 g of chironomid larvae. Since various amounts of the food organisms were regurgitated, the actual weights retained ranged from 0.02 g to 0.30 g and the digestion rates ranged from 2 to 26 mg of larvae evacuated per hour (Table 1). Digestion rates increased rapidly from 2 mg per hour when 20 mg of food were fed, to 22 mg per hour when 160 mg of food were fed. Digestion rate then increased less rapidly to a maximum of 26 mg per hour when 300 mg of food were fed. These data suggest maximum digestion rate was being approached when further increase in weight of food fed beyond 300 mg would not increase digestion rate much above 26 mg per hour.

Changes in digestion rate with time were observed since 2, 4, 6, 8, 10, and 12 hr. were allowed for digestion (Table 2). Digestion rate decreased from 15.7% stomach evacuation per hr. 2 hours after force-feeding to 8.1% per hr. after 12 hours.

Table 1. Digestion rates expressed as milligrams of chironomid larvae evacuated by the stomach per hour for bullheads force-fed various amounts of chironomid larvae.

Weight fed (mg)	Number fish	Digestion rate (mg/hr) Minimum	Maximum	Mean
20	2	1	2	2
30	1	5	5	5
40	2	5	5	5
50	3	1	8	5
60	2	8	10	9
70	4	9	20	14
80	3	9	10	10
90	4	10	25	17
100	1	30	30	30
130	2	14	16	15
140	2	13	22	18
160	2	20	24	22
170	1	25	25	25
180	4	15	22	18
190	7	15	32	20
200	14	14	45	23
230	2	18	24	21
240	2	20	25	23
250	2	24	28	26
260	2	20	25	23
270	3	14	27	21
280	2	19	26	23
290	4	12	28	22
300	3	24	28	26

Table 2. Digestion rates and percentage stomach evacuation for force-fed bullheads allowed to digest for different lengths of time.

Time allowed for digestion (hour)	Number fish	Digestion rate (percentage evacuation/hour) Min.	Max.	Mean	Percentage evacuation Min.	Max.	Mean
2	14	5.5	30.0	15.7	11.1	60.0	31.4
4	13	9.6	25.0	15.4	38.5	100.0	61.5
6	15	7.9	16.7	11.7	47.4	100.0	70.4
8	14	2.5	12.5	9.6	20.0	100.0	76.6
10	10	6.8	10.0	8.8	67.9	100.0	88.1
12	8	7.1	8.3	8.1	85.0	100.0	96.8

As time progressed, the percentage evacuation of the stomach increased from 31.4% at 2 hours after force-feeding to 96.8% after 12 hours (Table 2).

Since the amount of food digested depended on both the weight of food fed (Table 1) and the time allowed for digestion (Table

2), regression analysis was used to determine the variation in digestion with each variable. Logarithmic (base 10) transformed measurements of weight of food recovered and time allowed for digestion indicated that 29% (r^2) of the variability was attributed to time. An anlysis of covariance was performed on nontransformed and logarithmic measurements of grams of food recovered (Y), grams of food fed (X_1), and hours allowed for digestion (X_2). With logarithmic (base 10) transformation of Y and X_2, 68% (R^2) of the variation was accounted for, but without transformation, 80% (R^2) of the variation was accounted for. The equation expressing the relationship was: $Y = 0.051 + 0.544 X_1 — 0.014 X_2$.
A t-test of significance for each regression coefficient was significant at the 99% level (Chamberlain and Jowett, 1968).

Interaction of weight fed and time was similar for the relationship expressed as digestion rate rather than as weight of food recovered. A regression analysis on the logarithmic (base 10) scale showed 70% (r^2) of the variation in digestion rate was related to the weight of food fed. An analysis of covariance of digestion rate (Y) in grams of chironomid larvae evacuated by the stomach per hour plotted against hours allowed for digestion (X_1) and grams of food fed (X_2) without transformation accounted for 55% (R^2) of the variation. With logarithmic (base 10) transformation of Y and X_2, 77% (R^2) of the variation was accounted for and the equation was: $\text{Log } Y = -0.978 — 0.22 X_1 + 0.803 \log X_2$.
A t-test of significance on each regression coefficient was significant at the 99% confidence level (Chamberlain and Jowett, 1968).

In higher animals such as man, distention of the stomach increases secretion of digestive juices and motility of the gut (Guyton, 1961). By using the equation presented for computing digestion rate, bullhead digestion rate increased 2.4 times as the size of the meal was tripled. Digestion rates for bluegill sunfish increased 2.2 times when the size of the meal (*Tenebrio molitor larvae*) was increased 2.7 times (Windell, 1966). Wendell's fish were not force-fed. Hunt (1960), working with Florida gar (*Lepisosteus playhrincus*), found that the digestion rate increased 2.2 times when the size of the force-fed meal (*Gambusia*) was increased slightly more than three times.

Digestion Rate Under Natural Conditions. Digestion rates were determined with Bajkov (1935) method for two random samples of 55 fish each having total lengths from 8.0 to 12.2 cm. Stomach contents were mostly detritus, chironomid larvae, and some fish fry. Weights of food recovered from the two samples of fish decreased similarly as time progressed (Table 3). Mean weight of food recovered decreased from 49 mg at time of capture to 6 mg 8 hours after capture. Unlike the laboratory experiments, the

amount of food originally consumed was not known and an analysis of covariance could not be performed. A regression analysis of the mean grams of food recovered (Y) and the hours allowed for digestion (X) showed that: $Y = 0.042 - 0.005 X$.
The r^2 value of 0.88 indicated that 88% of the variation in weight of food recovered was related to the time allowed for digestion. Digestion rate was apparently slower for fish in the lake, probably because of the different kinds of food.

Table 3. Mean weights of food recovered from the stomachs of 110 bullheads examined at 2-hour intervals after capture by seining in Clear Lake, Iowa during August, 1968.

Time after capture (hour)	Mean weights recovered (mg) Sample 1	Sample 2	Mean
0	56	43	49
2	29	23	26
4	15	18	16
6	8	16	12
8	2	11	6

Daily Food Consumption Determined in the Laboratory. Daily food consumption was measured for 9 days in turbid lake water (25 to 28 C) and 6 days in non-turbid tap water (20 to 23 C). Tap water in Clear Lake, Iowa consists of filtered and alum treated lake water. Since tap water was filtered to remove chlorine, it was similar to lake water except for lower turbidity, and possibly, some residual chemicals from the alum treatment.

In both turbid and non-turbid water, fish receiving 6% rations consumed more food than fish receiving 3% rations (Table 4). In non-turbid water, fish offered 3% rations consumed an average of 1.3% of their body weight in food per day and fish offered 6% rations averaged 3.6%. In turbid water, fish offered 3% rations consumed all food offered and fish given 6% rations consumed 5.6% of their body weight in food per day. Daily food consumption definitely increased when food was more abundant. Unfortunately, it was not possible to fully compare food consumption in turbid and non-turbid water because temperature could not be adequately controlled. Daily food consumption in turbid water was almost double food consumption in non-turbid water but mean temperature of the turbid water was 26.5° C, in contrast to 21.5° C in non-turbid water. In one study, 10° C rise in temperature doubled the rate of food passage through the bullhead (Darnell and Meierotto, 1962).

Daily Food Consumption Determined in the Lake. Natural feeding rate of bullheads is affected by social behavior, feeding

Table 4. Size of fish, daily food rations, and feeding rates of fish kept in non-turbid water at 20 to 23° C and in turbid water at 25 to 28° C.

Daily food ration	Weight of fish (g)	Weight of daily ration (g)	Mean daily food consumption (g/day)	Mean percentage body weight of daily ration consumed
	10.4	0.31	0.19	1.7
3%	11.5	0.35	0.12	1.0
	10.6	0.32	0.10	1.0
body				
	11.5	0.34	0.10	0.8
weight	11.0	0.33	0.22	1.9
	13.9	0.42	0.18	1.3
	11.8	0.70	0.22	2.3
6%	10.0	0.60	0.40	4.0
	11.8	0.71	0.34	2.9
body				
	10.9	0.65	0.51	4.7
weight	9.2	0.55	0.34	3.7
	7.8	0.47	0.31	4.0
Turbid water				
3%	6.5	0.20	0.20	3.0
body	8.2	0.24	0.24	3.0
weight	7.3	0.22	0.22	3.0
6%	6.6	0.40	0.38	5.8
body	6.2	0.37	0.37	6.0
weight	6.8	0.41	0.35	5.1

periodicity, kinds of food, food availability, and other environmental conditions that are difficult to duplicate in the laboratory. To compare natural feeding rates with laboratory feeding rates, 204 fish were randomly sampled during 24 non-consecutive hours over a 3-day period in August, 1968. Fish sampled for the food consumption experiments had an average weight of 13.7 g and an average total length of 10.1 cm. Stomach contents consisted mainly of chironomid larvae, vegetation, adult insects, fish fry, and detritus.

For the entire 24-hour period, fish had an average of 0.24 g of food in their stomachs, which was equivalent to having 1.78% of their body weight present as food at all times (Table 5). Using the equation determined in the force-feeding digestion rate experiments ($\log Y = -0.978 - 0.022X_1 + 0.803 \log X_2$), and assuming 0.24 g of food were eaten and one hour was allowed for digestion, the digestion rate would be 0.032 grams per hour. Therefore, over a 24-hour period, each fish would theoretically consume 0.77 g of food or approximately 5.6% body weight. This feeding level was exactly equal to the 5.6% body weight feeding level found at the same lake water temperatures in the laboratory for fish eating chironomid larvae.

Table 5. Number of fish sampled and mean weight of food found in the stomachs of 204 Clear Lake yearling black bullheads during August 20 to 22, 1968.

Sampling time	Number fish	Mean weight of food in stomach (g)
a.m.		
8:00	11	0.13
9:00	11	0.10
10:00[a]	—	0.11
11:00	11	0.13
12:00[a]	—	0.14
p.m.		
1:00	11	0.15
2:00[a]	—	0.20
3:00	11	0.25
4:00[a]	—	0.40
5:00	10	0.54
6:00[a]	—	0.34
7:00	9	0.14
8:00	11	0.21
9:00	10	0.11
10:00	11	0.10
11:00	11	0.35
12:00	10	0.37
a.m.		
1:00	11	0.56
2:00	11	0.52
3:00	11	0.25
4:00	11	0.24
5:00	11	0.21
6:00	11	0.16
7:00	11	0.11

[a]The mean weight of food in the stmachs for this time period was interpolated from the curve in Fig. 1.

Feeding Chronology. Carlander and Cleary (1949) and Carlander (1953) found that bullheads in Clear Lake were more active during night than during the day. The active period began at 8:00 PM and subsided at 6:00 AM. Jude (1968), working on the Mississippi River, found bullhead feeding and activity periods both reached peaks at 4:00 to 6:00 AM. Darnell and Meierotto (1965) found extensive feeding activity of adult bullheads at night between 8:00 PM and 4:00 AM, while young bullheads fed extensively in the morning between 2:00 AM and 5:00 AM and at night between 8:00 PM and 11:00 PM. They noted also that young bullheads ingested very little food during the day between 11:00 AM and 5:00 PM. The yearling bullheads used for determining feeding rate in Clear Lake also showed a diurnal cycle in feeding activity (Table 5) with peaks at 1:00 AM and 5:00 PM (Fig. 1). Very little feeding activity was observed from 6:00 AM to 1:00 PM and from 7:00 PM to 10:00 PM when stomach contents weighed less than 0.2 g.

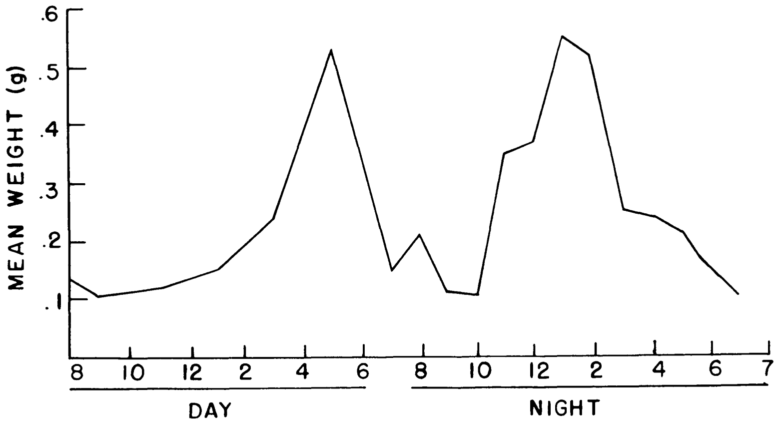

Figure 1. Mean weight of stomach contents of black bullheads collected at 1- to 2-hour intervals, Clear Lake, August, 1968.

Discussion

Food consumption experiments in the lake and in lake water in the laboratory indicated that bullheads consumed an average of 5.6% of their body weight in food per day when water temperatures were between 25 and 28° C. Hence, a yearling bullhead having a mean weight of 13.7 g could consume an average of 0.77 g of chironomid larvae per day. Chironomid larvae used in the laboratory experiments averaged 228 larvae per gram. If each fish consumed 0.77 g of these chironomid larvae daily, approximately 175 larvae would be eaten each day by each fish.

A limited number of dredge samples taken in Clear Lake revealed chironomid larvae in the lake were much larger than those used in the laboratory experiments. Stomach contents of fish caught in the lake showed chironomid larvae (*Tendipes tentans*) (Forney, 1955) to be the major food item in the bullhead diet. Since the size and the species of chironomids used in the laboratory differed from those found in the lake, the amount of chironomids eaten in the lake would be below the estimated 175 larvae.

Mrachek and Bachmann (1967) found chironomids were the most abundant benthic organism and estimated the summer standing crop of benthic organisms in Clear Lake to be about 79 kg per hectare. Considering the great abundance of black bullheads in Clear Lake, it is probable that they consume considerable amounts of food that would otherwise be available to more desirable species.

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